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## **Ammonia Emissions from U.S. Broiler Houses in Kentucky and Pennsylvania**

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**Abstract.** *Updated U.S. broiler ammonia emissions for PA and KY are presented.*

**Keywords.** Emissions, ammonia, poultry, ventilation, electrochemical, litter treatment

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## Abstract

*Twelve commercial broiler houses in the United States were each monitored for thirteen 48-hour periods over the course of one year to obtain ammonia emission data. Houses on four farms in two states included paired repetition of houses chosen to represent the variety in modern construction, litter management practices, and climate conditions. Ammonia concentration was determined by portable monitoring units incorporating electrochemical sensors with a fresh air purge cycle. Ventilation rate was determined via in-situ measurement of fan capacity versus static pressure difference of all fans in each house using an anemometer array. During each study period, fan on-off times and house static pressure difference were monitored.*

*There were seasonal trends in house ammonia concentration and ventilation rates but offsetting relationships between these two factors resulted in fairly uniform ammonia emission rates from flocks over the seasons. Emission rates were highest during periods of warmest weather, especially with larger birds. The best predictive relationship for emission rate was found between average daily emission rate per bird and flock age. Emission rate per floor area versus flock age acknowledges the ammonia emission surface area, and offered another good predictive relationship. Emission rate in terms of animal unit (500 kg) for built-up litter flocks indicated very high emissions per AU for the youngest birds (under about 10 days of age), after which time the emissions were relatively steady for the balance of the flock cycle.*

*Flocks that had at least three monitoring periods (13 of 22 flocks studied) provided emission rates that were very similar among the four study farms and across the seasons (regression slope average  $0.031 \text{ g NH}_3 \text{ bird}^{-1} \text{ d}^{-1}$  per day of age; std. dev. 0.0057). When all flock data from each farm was analyzed as a composite, for the three farms with built-up litter the predicted regression slopes were 0.028, 0.034 and  $0.037 \text{ g NH}_3 \text{ bird}^{-1} \text{ d}^{-1}$  per day of flock age; the fourth farm had new litter for each flock resulting in the lowest emission rate of the study farms at  $0.024 \text{ g NH}_3 \text{ bird}^{-1} \text{ d}^{-1}$  per day of flock age. The intercept of these composite linear relationships was influenced by litter conditions with flocks on new litter having essentially no emissions for about 6 days while built-up litter flocks had an intercept near 0.*

## Introduction

Reasonable estimates of ammonia emissions are needed by the poultry industry so that they can participate in discussions about their industry's impact on local and regional air quality. There are a limited amount of scientific estimates of ammonia emissions from U.S. poultry facilities despite the interest of agencies and concerned citizen groups in mitigating ammonia emission from livestock facilities (National Academy of Science, 2002). Although in many ways broiler houses appear to be similar throughout the U.S., there are differences in housing styles, management, equipment selection, bird husbandry, and maintenance that provide large differences in effectiveness of the environmental control system performance in the houses, which in turn effects emission rate.

Emission rate is the product of ammonia concentration and ventilation exhaust airflow rate. While this calculation is simple in concept, in practice, both concentration and ventilation are difficult to measure accurately within commercial poultry house conditions. Mechanically (fan) ventilated facilities should in principle be more easily monitored than naturally ventilated facilities for ventilation rate by determining fan capacity and runtime. Ammonia instrumentation suffers from the challenges of high cost for highly accurate models or inconsistent accuracy and reliability for more affordable sensor technologies (Gates et al., 2004a). Emission rate from

livestock housing is often expressed in terms of mass of ammonia release per mass of animal housed over a given time period. Broiler chicks, initially weighing about 40 g each when placed in housing, grow rapidly into 2-3 kg market weight birds. Thus, both number and weight of birds need to be known in determination of the emission rate.

## Methods

### *Study Houses*

#### Overall

Environmental conditions in twelve commercial broiler houses in the United States (Kentucky, and Pennsylvania) were monitored during thirteen, 48-hour periods over the course of one year. The monitoring periods provided data to determine ammonia emission from the broiler houses during different seasons with various age birds during at least five flock grow-out cycles. In order to economically obtain data from as many houses as possible over the year, the instrumentation was taken to one set of houses the first week and another set of houses the second week. The interval between 48-hour collection periods was typically three weeks in PA and two weeks in KY, with the third week being spent in data organization, instrumentation checks, and time to thoroughly disinfect for biosecurity. A “day” of data collection started when all the instrumentation was installed in the house and ended 24-hours later. Four of the study houses were in PA representing a “cold” climate and eight were in KY representing a “mixed humid” climate. Average 30-year heating degree days 18.3°C base is 3250 and 2625 (65°F base is 4200 and 5200), KY and PA, respectively, based on the nearest available climate data (NCDC, 2000). Farms were selected to represent the variety in modern broiler production practices, including those that practiced methods that were presumed to reduce ammonia emissions.

#### Cold climate houses

The four PA houses were paired, for repetition of conditions, on two farm sites (Farm B and H), with different managers, under contract to different companies. These houses were each 14.6 m wide x 152.4 m long (48 ft x 500 ft) and housed a nominal 32,500 or 32,700 birds during cold weather, Farm B and Farm H, respectively. Placement density was 14.6 or 14.7 birds m<sup>-2</sup> (1.35 or 1.36 birds ft<sup>-2</sup>), Farm B and Farm H, respectively. All four were recently built (2000-2001) at the time of the study by the same construction company and were identical for purposes of this study. Houses had fully-insulated suspended ceilings and insulated stud wall construction. They had the same ventilation system design including fan model specifications (ten 127 cm (50 in. 1 hp, belt drive, GSI Group #5021) and four or five 91 cm (36 in. ½ hp, belt drive, GSI Group # CGBB3641) diameter fans), eave box-inlet design and placement (automatically static pressure controlled; Cumberland Auto Air Sensor w/ Dwyer Photohelic and two AirStream Curtain Controllers for box inlets and tunnel curtain), and environmental computer controller (Chore Time Super Selector PNT). House tightness evaluated with a static pressure test using one 91 cm exhaust fan with house doors and windows closed was 55 Pa (0.22 in. water) for Farm B in winterized condition (unused fans and tunnel inlet openings sealed) and 20 Pa (0.08 in. water) for Farm H without winterization. Farm H practiced whole house brooding, while Farm B used partial house brooding. Farm B used radiant brooders in two lines in the brood section along with space unit heaters throughout the entire house. The heaters were thermostat controlled rather than being part of the computer environmental controller functions. Farm H used

pancake-style brooders in a single line along the length of the entire house as the only heat source; they were controlled by the computer controller.

### Southern climate houses

Two KY sites were monitored, each with four houses, for replications of conditions. Each site was under contract to a different integrator company. Insulated, suspended ceilings were used in all houses. Each broiler house was 12.2 m x 152.5 m (40 x 500 ft; except House 4 at Site 1, which was 12.2 x 157.4 m (40 x 516 ft)) and with a nominal 20,000 or 25,000 birds, dependent upon finished bird requirements. This produced a placement density of 13.44 birds m<sup>-2</sup> at 25,000 birds placed and 10.75 birds m<sup>-2</sup> at 20,000 birds placed. The houses at Site 1 were built in 2000 (except House 4, which was built in 1995) while those at Site 2 were constructed in 1997. All houses at both Site 1 and Site 2 had an opening along the full length of both sidewalls covered by a single-layer curtain for emergency ventilation (curtain vertical opening Site 1 was 120 cm, Site 2 was 67 cm ).

At Site 1, each house had eight 122 cm fans (Choretime 38233-2 48 in. Turbo Fan (BD)) and three 92 cm fans (Choretime 38232-2 36 in. Turbo Fan). Box inlets were located along both sidewalls and were automatically controlled based on static pressure difference. The ventilation system at this site was controlled by an electronic controller (Choretime, Milford, IN). A single 122 cm fan in a non-brood section of each house was used for minimum ventilation. Pancake-style brooders were used in the brooding end and unit space heaters in the non-brood end.

At Site 2, ventilation fans included eight 122 cm diameter fans (Hired-Hand Econo-Flow 48 in. Direct Drive Panel Fan) and six 92 cm diameter fans (Hired-Hand Econo-Flow 36" Direct Drive Panel Fan) in each house. Box inlets were located along both sidewalls and were automatically controlled via cable based on maintenance of setpoint static pressure difference. The ventilation control system at this site used individual thermostats on each fan and unit space heaters (six Hired-Hand Super Saver XL in the brooding area only). Each of the six 92 cm fans was equipped with a ten-minute electro-mechanical cycle timer. These cycle timers were only active on the two 92 cm fans being used for minimum ventilation, which were located in the non-brood sections at opposite ends of the house, set to either 3 or 5 minutes ON during the 10-minute cycle. The central section of the house was used for brooding.

### Manure Handling

New litter is typically provided once a year in U.S. broiler houses with caked litter under feeders and drinkers removed after each flock. This practice is often referred to as 'built-up' litter in the industry and is a combination of the original litter material and accumulated manure; sometimes limited fresh litter is incorporated before each new flock is placed. Table 1 features litter conditions at the 12 study houses over the studied flock cycles.

The primary difference between the two PA study locations was that Farm H houses had concrete floors and new litter each flock while Farm B had built-up litter on dirt (crushed shale) floors. Farm B's second study flock was on new litter after the annual litter cleanout. New litter for both PA farms was kiln-dried wood shavings provided at a depth of 3 cm at Farm H and 7 cm at Farm B. By the end of five flocks use at Farm B, with caked litter removal, litter was about 8 cm deep. For flocks with cold-weather start dates, Farm B incorporated a 0.243 kg m<sup>-2</sup> (50 lb 1000 ft<sup>2</sup>) litter treatment of either PLT™ or Poultry Guard™ to litter lower pH in the brood section on both houses on the day before chick placement. Additional litter treatment was

applied in the non-brood section of the house, at the same application rate, the day birds are moved into that section.

All KY houses employed built-up litter; some used a litter amendment to reduce ammonia volatilization. At Site 1, NaHSO<sub>4</sub> was applied at 0.244 kg m<sup>-2</sup> to the litter of the brooding section prior to chick placement in the period November through March. At Site 2, PLT<sup>TM</sup> was applied in the brooding area prior to placement only in houses 1 and 2 at rate of 0.226 kg m<sup>-2</sup> (46 lb 1000 ft<sup>-2</sup>).

### Ventilation strategies

All study houses were equipped with essentially two mechanical ventilation systems that shared a common controller (in the case of computer controlled houses). One ventilation system used sidewall fans and eave inlets for cold and mild weather environmental control and the second used end-to-end airflow with large inlets and fans for “tunnel” ventilation. Endwall fans were also used for mild weather ventilation prior to switching to tunnel ventilation. During the hottest weather, the ventilation system switched from using sidewall inlets and fans to the tunnel ventilation mode. Particularly for the first two flocks that were during cold weather, the broiler houses were under minimum ventilation to maintain indoor moisture level and air quality. Minimum ventilation settings were also used with young birds. The U.S. broiler industry typically provides minimum ventilation through timer-controlled fan operation. Timer ‘on time’ was increased as the birds grew in size to coincide with increased respiratory and excreted moisture levels. The tunnel ventilation strategy was used during the warmer portions of study periods reported here.

Table 1. Flock placement start dates and litter conditions, the latter expressed as flock rank using that litter (1 being new litter). Superscripts indicate house number. Study year starts in late 2002 with most flocks monitored during 2003. Missing early flock dates were during study start-up when incomplete data prevents full analysis. Asterisk indicates flock using litter treatment.

Kentucky						Pennsylvania					
Site 1			Site 2			Farm B			Farm H		
Flock No.	Start	Litter	Flock No.	Start	Litter	Flock No.	Start	Litter	Flock No.	Start	Litter
4	Nov 28	4 <sup>1,3*</sup> 3 <sup>2,4*</sup>				1	Jan 1	5*	1	Dec 4	1
5	Jan 27	5 <sup>1,3*</sup> 4 <sup>2,4*</sup>	2	Nov 28	2 <sup>1,2*</sup> 2 <sup>3,4</sup>	2	Mar 6	1*	2	Feb 3	1
6	Mar 26	1 <sup>1</sup> 6 <sup>3*</sup> 5 <sup>2,4*</sup>	3	Feb 11	3 <sup>1,2*</sup> 3 <sup>3,4</sup>	3	May 1	2	3	Apr 8	1
7	May 26	2 <sup>1</sup> 1 <sup>2,3,4</sup>	4	Apr 17	4 <sup>1,2*</sup> 4 <sup>3,4</sup>	4	Jun 18	3	4	Jun 9	1
8	Jul 24	3 <sup>1</sup> 2 <sup>2,3,4</sup>	5	Jul 01	5 <sup>1,2*</sup> 5 <sup>3,4</sup>	5	Aug 15	4	5	Aug 13	1
9	Sep 22	4 <sup>1</sup> 3 <sup>2,3,4</sup>	6	Sep 15	1 <sup>1,2*</sup> 1 <sup>3,4</sup>	6	Oct 10; 14	5*	6	Oct 14	1

## Flock characteristics

Bird weights over the entire growth cycle and house population were needed for emission estimates per kg bird weight (housed, not capacity), per bird, and per 500 kg animal unit (AU) housed. Bird weights for age were obtained from the integrator companies in KY who had recent field data from electronic or manual weighing of portions of similar flocks. PA bird weights were estimated from field data on birds of the same strains (Cobb-Cobb, Ross Arbor Acre or Cobb-Ross Arbor Acre) in PA during a previous study (Wheeler et al. 1999). PA bird weights were obtained by weighing 1% of the total bird population in that study's four houses every week over a winter flock cycle. The four houses were on three different broiler farms. Birds were caught as a group by surrounding a portion of the flock with a portable pen to capture a representative sample of large, small, fast and slow individuals. Birds were weighed in-house on a portable electronic scale. All data were combined for analysis of bird weight versus age. Linear regression equations were created to represent the PA houses with one relationship for young birds and another for older birds. Similar linear regressions were created for the two sets of KY bird weight data to represent birds at each site. Actual bird population numbers were used in PA data to reflect chick placement number on day 1 minus mortality and culls as the flock aged. KY data are presented in terms of initial bird placement numbers.

## Instrumentation

### Ammonia measurement

Portable Monitoring Units (PMUs) were designed to monitor ammonia and carbon dioxide concentrations and static pressure difference between interior and exterior conditions. Detailed information about the design and performance of the PMU were described by Xin *et al.* 2002, Xin *et al.* 2003 and Gates et al. 2004a. Briefly, the PMU was a tight-closing panel-box that held instrumentation for emissions data collection that was portable and cleanable for use in multiple houses. It was wall-mounted near the monitored exhaust fan. At least one PMU was installed in each broiler house during a study period to monitor conditions of exhaust air and fresh outside air. Instrumentation within the PMU included two identical sensors for redundancy of ammonia concentration (0-200 ppm; PAC III, Draeger Safety, Inc, Pittsburgh, PA) with plumbing and controls (pump, solenoid valve, flow meters for controlled flow) for cycling fresh, outside air (24 minute duration) and poultry house air (6 minute duration) past the sensors within a 30-minute interval. The electrochemical sensors were purged with fresh air to reduce sensor saturation from continuous ammonia exposure. These sensors read ammonia concentration every second and were set to record the time averaged reading once per minute.

### Ventilation Rate Parameters

Each PMU also monitored other parameters needed for ventilation rate determination. Static pressure difference (0-125 Pa, 0-0.5 in. water, Model 264, Setra Systems, Inc, Boxborough, MA) was used in calculation of ventilation rate (described below). Carbon dioxide concentration (infrared transmitter, 0-5000 +/- 20 ppm, Model GMT222, Vaisala, Inc., Woburn, MA) was used as a fresh air indicator for purge air and as a second method of estimating ventilation rate (Li et al., 2004). Each electrochemical ammonia sensor had an integral datalogger that was temperature corrected. The other sensor outputs (solenoid switch of fresh-purge air, CO<sub>2</sub> sensor, sample gas temperature near the sensors, and static pressure difference) were recorded with a 4-channel battery-operated data logger (4-20 mA +/- 0.1%, Onset Computer Corporation, Bourne, MA).



### ***Instrumentation position***

Two PMUs were typically installed in each house. One PMU, which was equipped with the building static pressure sensor, was located near and monitored the primary minimum ventilation fan. The second PMU was installed near a second minimum ventilation fan, if that fan was located in another chamber of the house. On some occasions, the primary minimum ventilation fan was in an unheated non-brood chamber of the house and in other instances it was in the heated brood area. More commonly, the second PMU was located next to one of the larger “tunnel” fans to record emissions when these fans were in operation and the sidewall fans were off. PMU placement depended on farm manager’s seasonal ventilation scheme during the 48-hour study period.

Air samples were drawn into the PMU through two lengths of polyvinyl-chloride 9 mm (3/8-inch) o.d. transparent flexible tubing (6 mm; 1/4-inch i.d.). The house air tube was 2-3 m long with air intake positioned in front of the monitored exhaust fan (1/3 fan diameter down from top, 15cm horizontal offset from fan center, 45cm in front of fan intake) and was equipped with a 20 micron paper filter (Whatman 41 cat. no. 1441047). The purge air line intake was positioned outside the poultry house, at the eaves in between fresh air inlet boxes on the house sidewall that did not have exhaust fans and was equipped with an automotive-style pleated-paper air filter. Filters were used to exclude larger particulates and insects from clogging the air collection lines.

The static pressure equipped PMU had a detection tube that was positioned outside the poultry house, at the eaves in between inlet boxes on the house sidewall where the PMU was hanging. At the eaves, the tube terminated inside a 2 liter plastic bottle to minimize the effects from wind gusts on the recorded building static pressure. Interior static pressure was monitored at an open port on the PMU.

Indoor and outdoor temperature and relative humidity were monitored. A pair (for redundancy) of combined temperature/relative humidity detectors ( $\pm 0.4^{\circ}\text{C}$  [ $\pm 0.7^{\circ}\text{F}$ ] and  $\pm 3\%$  RH in standard resolution mode at temperature range under study, HOBO Pro Series, Onset Computer Corporation, Bourne, MA) were placed approximately at the house center about 60cm above the litter surface (above bird reach) with another pair outside under the building eave protected from direct sunlight and away from exhaust fans.

### ***Fan Ventilation Rate***

Ventilation rate was calculated using actual fan performance and run-time data. Data recorded included static pressure difference of the ventilation system every minute and fan on-time using motor loggers every second (see below). Data were averaged into 30-minute intervals for analysis. In addition, to correct for standard atmospheric conditions, house temperature at bird-level was averaged into half-hour values, and site elevation (PA) and barometric pressure (KY) from weather station (HOBO Weather Station with Barometric Pressure Smart Sensor ( $\pm 0.29$  kPa), Onset Computer Corporation, Bourne, MA) were used to correct to standard temperature ( $0^{\circ}\text{C}$ ) and pressure (101.325 kPa).

Fan run time was monitored at each fan with on/off motor loggers (HOBO on/off motor, Onset Computer Corporation, Bourne, MA), installed on electric cable “pigtailed” between the electric supply receptacle and plug to each fan. These loggers provided time of state change each second with a resolution of 0.5 second.

The “actual” exhaust fan ventilation capacity was determined *in situ* with a traversing anemometer array, the Fan Assessment Numeration System (FANS) unit (Gates *et al.* 2004b;

Casey et al., 2002). In short, the FANS consisted of five vane anemometers positioned on a bar that traversed the entire airflow entry area to each fan. The FANS was used to develop performance curves for each individual fan in each house (11, 14 or 15 fans per house) over a range of six typical building static pressure differences (0 to 50 Pa, 0 to 0.18 in. water). The FANS was positioned on the intake side of the fan of interest and sealed against air leaks. Wheeler et al (2002) has detail of FANS use in field evaluations of fan ventilation capacity. All tests were done when the house had no birds present so that any ventilation condition could be evaluated without jeopardizing bird comfort.

It took about 1 hour to fully evaluate each fan over the range of typical operating static pressure (SP) differences so several trips to each farm were necessary to fully characterize each houses' ventilation system. In PA and Site 2 in KY, house static pressure was monitored and controlled during the fan capacity trials via the house environmental controller's static pressure instrument (Photohelic, Dwyer Instruments, Michigan City, IN). In PA, this Photohelic was checked and zeroed (if necessary) before testing began. In KY at Site 2, Photohelic calibrations were checked (Furness Controls Limited, Portable Pressure Calibrator PPC 500) following testing and a correction applied to data as required. The SP setpoint needles on the Photohelic instrument were set to within about 1 mm of each other so that SP was kept in a very narrow range by the inlet controller. Once the SP stabilized, a FANS traverse was run and recorded for KY houses since early testing revealed negligible difference between replicated runs. In PA, a second traverse was run right away. If the difference between the two runs was more than 3%, another pair of traverses was completed. This was done as a precaution, especially during conditions when wind pressures could affect fan airflow capacity.

A similar, calibrated static pressure monitoring instrument (Magnehelic, Dwyer Instruments) was set up near the fan being evaluated by the FANS for additional validation of house static pressure. Fan ventilation rates were determined near the beginning of the study in PA. Additional tests near the end of the project indicated no measurable difference in fan performance over the yearlong study period for these fans that were cleaned between each flock.

At Site 2 in KY there were computer controllers, so static pressure was set by manually opening vents while monitoring SP (Dwyer Series 475 Mk III Handheld Digital Manometer, 0-1.00 in. water). During each test, SP was continuously logged (Setra Model 264 Differential Pressure Transducer connected to a Hobo H08-006-04 4 Channel Logger sampling at 1 second intervals) with the average SP determined for each traverse period.

Under minimum ventilation for air quality during cold weather the fan on-off times were known so that ventilation rate was a constant over the evaluation time period. Timer fan on-off time was provided by the farm manager and verified with electronic controller settings, timed observation of the timer fan, and with fan motor loggers.

Building ventilation rate was determined by multiplying fan capacity of each individual fan at the average operating static pressure over a half-hour monitoring interval by that fan's actual run-time during that 30-minute interval. All fans running during that time interval were summed for the total building ventilation rate. Each half-hour was summed over a 24-hour period. Reported ventilation data are the average rate in  $\text{m}^3 \text{hr}^{-1}$  per 1000 birds for that 24-hour period.

### ***Data integrity***

All ammonia sensors were calibrated immediately prior to each study field trip and checked for calibration upon return from the field. NIST certified gas (PA: Master Standard Mixture-Messer MG Industries, Morrisville, PA; KY: CEM-2 Daily Standard – Scott Specialty Gases, Plumsteadville, PA) was used for a two-point calibration with span dependent upon anticipated

ammonia concentration at the study sites. Zero-ammonia as nitrogen gas, nominal 20, 50 and 100 ppm ammonia gases were used. Any sensors that did not pass the post-field check were further evaluated and replaced if necessary from spare sensor inventory. All sensors heads in PA were replaced half-way through the 16-months of use (this included start-up months and additional months in layer hen facilities in addition to the 12-months in broiler houses) in an attempt to maintain sensor integrity. In KY, a particular sensor was replaced when it was identified as defective or had been used for 60, 24-hour monitoring periods (determined from expected sensor life and exposure). Electrochemical sensors have a limited life and replacement cost was included in original project cost.

Pennsylvania calibration gases were certified during October 2002 with values: 18.6 ppm, 47.9 ppm, and 103 ppm. The gases were sent for recertification after one-year and re-certified during October 2003 for an additional year with values: 18.9 ppm, 48.3 ppm, & 104 ppm. The KY cylinders were within certification (12 months) during project period and not re-certified. Raw data from each state were shared with the other state to check for errors and omissions in calculations. Uniform parameters were agreed upon as were protocols for grooming the data from raw values to final emissions numbers. Even though the two research stations calculated emissions slightly differently in process, the end result was virtually identical when the same data were cross-checked using the two different methods during the quality control evaluation.

Determination of ventilation rate: Ventilation rate included all fan on-time events, even the short duration spikes in fan ON time for PA data but those spikes shorter than a 20-second duration were not used in KY data. The difference was minimal between the two methods. Calculation of fan run time was checked over two 24 hour periods for two cases. In the first case, the fans ran on a minimum ventilation program for almost the entire 48 hour period; in 228 minute run time in a 24 hour period, the maximum difference between the two calculation methods was 0.1 minute (0.05%). In the second case, the fans ran almost constantly during the 48 hour period; in 1440 minute run time in a 24 hour period, the maximum difference between the two calculation methods was 1 minute (0.07%).

Ammonia concentration: Selection of a correct ammonia value from raw data to represent the 30-minute interval was identical between the two stations. A representative ammonia value was selected from the 6-minute interval of house air to represent ammonia level in the house over the 30-minute house-purge air cycle. For each 30-minute interval, the house air values of both ammonia sensors were averaged for each minute and the maximum average ammonia concentration was chosen for use in calculation. Static pressure, house temperature, and outdoor temperature were the calculated average of all data over the 30-minute interval.

## **Results**

### ***Ammonia Concentration and Ventilation Rate per Flock***

Figures 1 to 4 provide individual flock ammonia concentration, ventilation rate (VR), and emission rate (ER) as daily averages for each house for each 24-hour study period. Some of the seasonality and correlation of ammonia concentration and ventilation rate become apparent with lower ammonia concentration and higher VR during warm summer conditions while ammonia concentration tended to be higher during cold weather when low ventilation rates provided less fresh air dilution of ammonia. Ammonia concentration, measured at building exhaust, increased with flock age in all PA houses (figures 1A and 2A), especially in the six flocks that started on new litter (all 5 flocks at Farm H and the second flock at Farm B) where initial ammonia level

was very low ( $< 10$  ppm). Higher ammonia levels later in each flock cycle were not anticipated for the PA used-litter houses (Farm B) since increased warm weather ventilation rates should have diluted building ammonia concentration. Interestingly, VR of the PA used-litter houses did not increase substantially as the flock aged until late summer and fall. But note that flock 3 during May was only monitored twice when birds were 3-4 and 20-21 days old where high VR would not be expected. (Note the VR versus bird age for all four farms are shown in figures 9 to 12.) The KY exhaust ammonia concentration (figure 3A and 4A) followed an increasing pattern with bird age for those flocks under winter conditions (Oct. – Feb.) but was steady or decreasing during the spring, summer and fall conditions when increasing ventilation rates were used later in the flock cycle (figure 3B and 4B). The results shown in parts A and B of figures 1 to 4 are the foundation data from which the emission rates were calculated.

### ***Emission Rate per Flock***

Individual flock emission rates are shown in figures 1C to 4C and provide evidence that ER can be relatively uniform flock to flock throughout the seasons despite the large variations in seasonal house exhaust ammonia concentration and ventilation rates. Highest ER was measured during the warmest weather. Regression equations for each flock curve are offered in terms of  $\text{g NH}_3 \text{ bird}^{-1} \text{ d}^{-1}$  versus flock age in days. The magnitude of each curve's slope can indicate the range of daily emission variability among these flocks. For flocks with at least three monitoring periods (13 flocks among all four sites) daily emission averaged  $0.031 \text{ g NH}_3 \text{ bird}^{-1} \text{ d}^{-1}$  per day of age (0.020 to 0.041 range; standard deviation 0.0057). In contrast, the flocks that experienced only two monitoring periods (9 flocks among all four sites, with 5 of those at Farm B) offered more variable results with a similar emissions slope average of  $0.037 \text{ g NH}_3 \text{ bird}^{-1} \text{ d}^{-1}$  per day of age but with a larger range (0.018 to 0.068) and standard deviation (0.0155). More variable results were due to a defined trajectory of the emissions rate data that did not necessarily reflect the influences of other phases of the flock cycle as were seen with three monitoring periods. Farm B had the most variable flock regression slopes averaging  $0.040 \text{ g NH}_3 \text{ bird}^{-1} \text{ d}^{-1}$  per day of age with range from 0.021 to 0.068. There would appear to be benefit in monitoring a flock for at least three study periods spread out over the course of the flock to obtain a reasonable emission estimate that represents the flock cycle. Intercept for these regression lines showed more variability than slope and were analyzed as part of the composite of all data from each flock.

### ***Daily Emission Rate per Bird versus Flock Age***

Figures 5 through 8 show ammonia emission results versus bird age as composites of all study dates at each of the four farms. Daily emissions are expressed as  $\text{g NH}_3 \text{ bird}^{-1} \text{ d}^{-1}$  versus bird age (days) in figures 5B to 8B. Regression  $r^2$  values for ER in  $\text{g NH}_3 \text{ bird}^{-1} \text{ d}^{-1}$  versus age were the highest among data relationships presented in this paper with three of the four farms above 0.82. Slope of regressions of all collected daily ER versus age for each study site were 0.028, 0.034 and  $0.037 \text{ g NH}_3 \text{ bird}^{-1} \text{ d}^{-1}$  per day of age for built-up litter flocks and  $0.024 \text{ g NH}_3 \text{ bird}^{-1} \text{ d}^{-1}$  per day of age for new litter flocks at Farm H. For sites with built-up litter, the intercept was near 0 days of age, (Site 1), equivalent of one-day ER (Site 2) and 2.4 days for Farm B. In contrast, the new litter farm has an intercept equivalent to six-day ER. These intercept equivalents are of interest when evaluating the flocks during early days in the cycle. For Site 1 the intercept of  $-0.017 \text{ mg NH}_3 \text{ bird}^{-1} \text{ d}^{-1}$  is equivalent to less than a minute of average daily emission (using regression slope of  $0.034 \text{ g NH}_3 \text{ bird}^{-1} \text{ d}^{-1}$ ), which is insignificant over a flock cycle. For Site 2 the intercept equivalent of about 1 day is still less than 2% of this 55-day flock cycle. For these built-up litter houses, the intercept may be dropped and emissions estimated with slope alone of  $0.028$  to  $0.034 \text{ g NH}_3 \text{ bird}^{-1} \text{ d}^{-1}$ . At placement of birds, considered 1 day old, there will be

ammonia emission on built-up litter. Further analysis of our data may reveal conditions where the higher or lower ER slope estimates should be used. For the new litter houses the regression intercept is an important component of the emissions estimation and essentially provides for “zero” emissions during the first six-days of the flock cycle (since negative emission is not possible) when little manure (ammonia) accumulates under the chicks and low VR were used. This 6-day period with virtually no emissions reduces the total house emission over the 45-day flock cycle at these study houses at the beginning of the flock and overall. Farm B also had a significant negative slope to the intercept equivalent to about 2.4 days of emissions. This farm manager used low ventilation rates during cold weather conditions and into warmer weather that may have influenced early flock emissions.

An estimate of daily NH<sub>3</sub> emissions per bird from these data is thus:

$$ER_b = 0.031(\pm 0.0057) \cdot x, \text{ where } x = \begin{cases} \text{age,} & \text{if used litter} \\ 0, & \text{if } 1 < \text{age} < 6; \text{age} - 6, \text{ if newlitter} \end{cases} \quad (1)$$

where

ER<sub>b</sub> = emissions rate, g NH<sub>3</sub> bird<sup>-1</sup> d<sup>-1</sup>

age = bird age, d

### **Emission Rate per Animal Unit**

An evaluation of daily ER in terms of 500 kg animal unit (g NH<sub>3</sub> AU<sup>-1</sup> d<sup>-1</sup>) are shown in figures 5a to 8A. For the PA houses, ER (g NH<sub>3</sub> AU<sup>-1</sup> d<sup>-1</sup>) for Farm H using new litter for each flock increased with increasing bird age (fig. 5A) while at Farm B on built-up litter the opposite occurred, ER per AU decreased with advancing bird age (fig. 6A). Further evidence for the strength of these trends is shown in figure 6A where the increasing trend in ER g NH<sub>3</sub> AU<sup>-1</sup> d<sup>-1</sup> with bird age on new litter is seen in flock 2, which started on new litter while the other flocks were started on built-up litter. Site 1 in KY also showed an influence of age, after 14 days, on decreasing ER per AU (figure 7A). Both PA and KY results indicated that there was generally no strong trend of bird age on ER per AU when birds were older than about 14 days of age. Site 2 houses had very high ER per AU early in the flock cycle after which time the trend settled into a pattern that did not vary with flock age (figure 8A). Other than at Site 1, after 14 days of age the regression relationship of ER expressed as g NH<sub>3</sub> AU<sup>-1</sup> d<sup>-1</sup> versus bird age was below 0.10 on built-up litter.

An estimate of daily NH<sub>3</sub> emissions per animal unit from these data is:

On built-up litter after 14 days bird age:

$$ER_{AU} = 400(\pm 200) \quad (2)$$

On new litter after 14 days bird age:

$$ER_{AU} = 225(\pm 50) \quad (3)$$

where, ER<sub>AU</sub> = emissions rate, g NH<sub>3</sub> AU<sup>-1</sup> d<sup>-1</sup>

## Floor-Based Emissions

Ammonia emissions originate from the manure deposited on the litter of the broiler house floor. Another way of expressing emission is in terms of the emitting surface, or floor area. Part C of figures 5 to 8 indicate that floor-based expression of emission rate per unit area is very similar in pattern to that expressed on a per bird basis versus flock age, with a similar  $r^2$ .

## Ventilation Rate Effects

One would expect that steadily increasing ventilation rates would result in steadily increasing emission rates (figures 9A to 12A) and this relationship was seen at all but one farm, Site 1. For all farms, low, fixed VR early in the flock (under about 10 day flock age) was predictable with the use of timer fans (figures 9B to 12B) and resulted in low ER from 1 to about 10 days (all farms but Site 2). Beyond about 10 days of age, higher VR generally resulted in higher ER at three of the four farms (not Site 1). All farms and flocks experienced increasing VR with bird age (fig. 9B to 12B) with much higher VR used in the warmer climate (KY) houses than in the cold climate (PA) houses.

## Emission Regulation

Figure 13 allows a quick conversion from daily ER as presented in this paper in g NH<sub>3</sub> per bird to pounds per house based on selection of bird population in that house. The emission rates found during this study indicate that a broiler house containing 20,000 to 30,000 birds managed using built-up litter is likely to be above the CERCLA ammonia threshold near the end of each flock cycle (40 to 60 days of age).

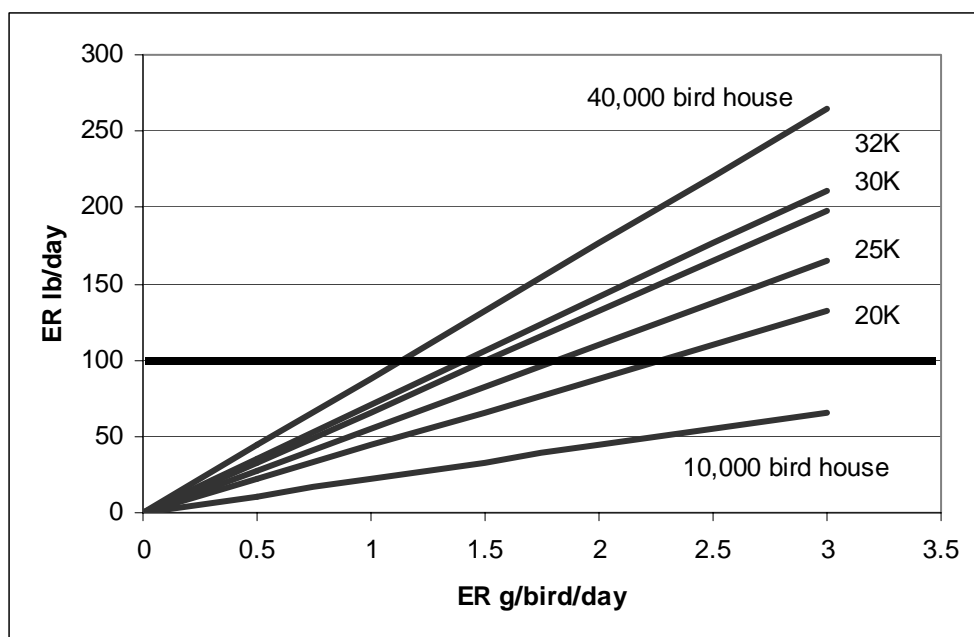


Figure 13. Daily ammonia emission rate conversion from grams per bird to pounds per house based on different house sizes, and associated bird populations, and ER estimate of that house. 100 lb/day CERCLA ammonia emission threshold is shown.

## Conclusions

The data presented here represent a significant advancement in characterizing baseline ammonia emissions from U.S. broiler facilities. There were seasonal trends in house ammonia concentration with generally higher values during cold weather periods that were times of relatively low ventilation rate. In contrast, the higher ventilation rates used during warmer seasons and with older birds generally resulted in lower house ammonia level. These offsetting relationships resulted in fairly uniform ammonia emission rates from flocks over the seasons, but with higher emission rate observed during hottest weather.

The best predictive relationship was found between average daily emission rate per bird and flock age. Another good relationship was found between emission rate per floor area versus flock age, which acknowledges the ammonia emission surface area.

Emission rate in terms of animal unit was usually independent of bird age after about 10 days of age. The relationship for built-up litter flocks indicated very high emissions per AU for the youngest birds (under about 10 days of age), after which time the emissions were lower and relatively steady for the balance of the flock cycle. For new litter houses the emission rate per AU was very low for the youngest birds and then higher and steady after 10 days of age.

Flocks that had at least three monitoring periods (13 of the 22 flocks used in this study) provided emission rates that were similar among the four study farms and across the seasons (regression slope average  $0.031 \text{ g NH}_3 \text{ bird}^{-1} \text{ d}^{-1}$  per day of age; std. dev. 0.0057). This is used to provide a predictive equation for daily emission (equation 1). Flocks with only two monitoring periods (9 flocks) had less uniformity among the predictive emission relationships (regression slope average  $0.037 \text{ g NH}_3 \text{ bird}^{-1} \text{ d}^{-1}$  per day of age; std. dev. 0.0155).

When all flock data from each farm were analyzed as a composite, the three farms with built-up litter had a predicted regression slope of 0.028, 0.034 and  $0.037 \text{ g NH}_3 \text{ bird}^{-1} \text{ d}^{-1}$  per day of flock age; for the fourth farm using new litter for each flock the slope was the lowest at  $0.024 \text{ g NH}_3 \text{ bird}^{-1} \text{ d}^{-1}$  per day of flock age. The intercept of these composite linear relationships was influenced by litter conditions with flocks on new litter having essentially no emissions for about 6 days while built-up litter flocks had an intercept near 0. Hence, emissions can be estimated as a simple function of bird age for these houses. Further analysis is needed that includes evaluation all new litter flocks, regardless of farm site, and evaluation of litter treatment effect on emissions.

## Acknowledgements

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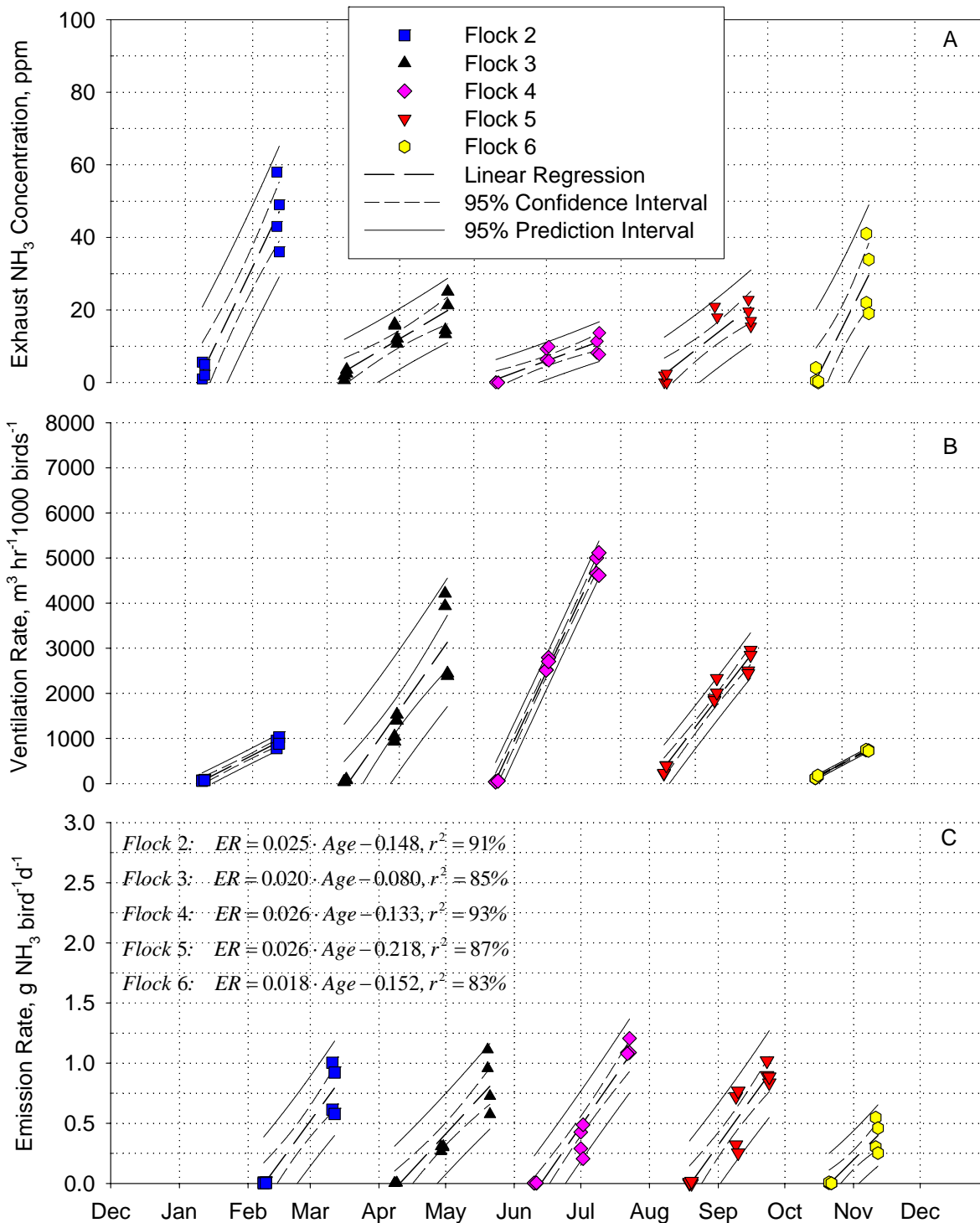


Figure 1. Individual flock presentation versus date for Farm H managed with new litter every flock. Average daily ammonia concentration (A) and ventilation rate (B) for each flock cycle over the one-year study period. Average daily emission rate per bird is shown in C with individual flock regression equations.

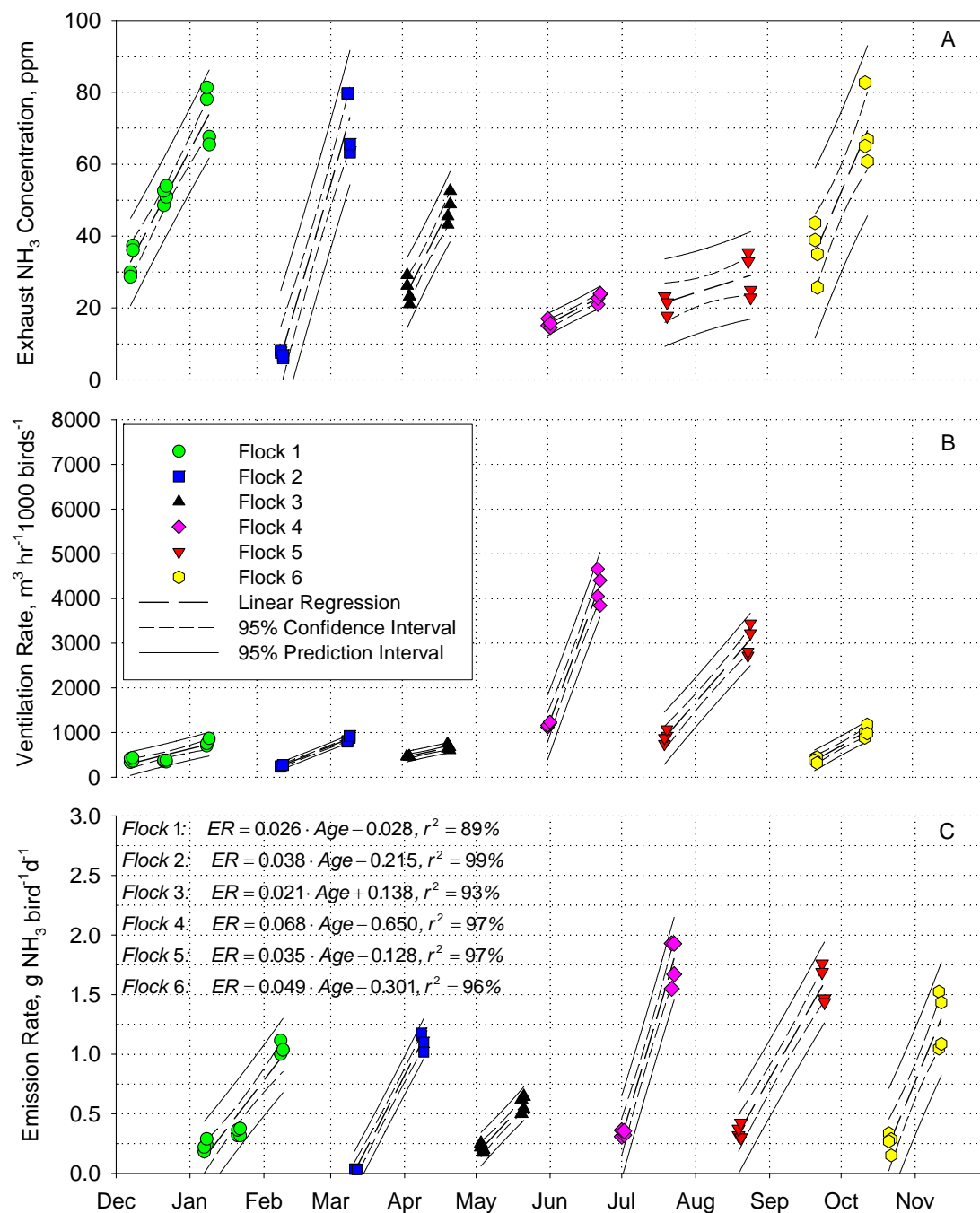


Figure 2. Individual flock presentation versus date for Farm B managed with built-up litter, except flock 2 on new litter. Average daily ammonia concentration (A) and ventilation rate (B) for each flock cycle over the one-year study period. Average daily emission rate per bird is shown in C with individual flock regression equations.

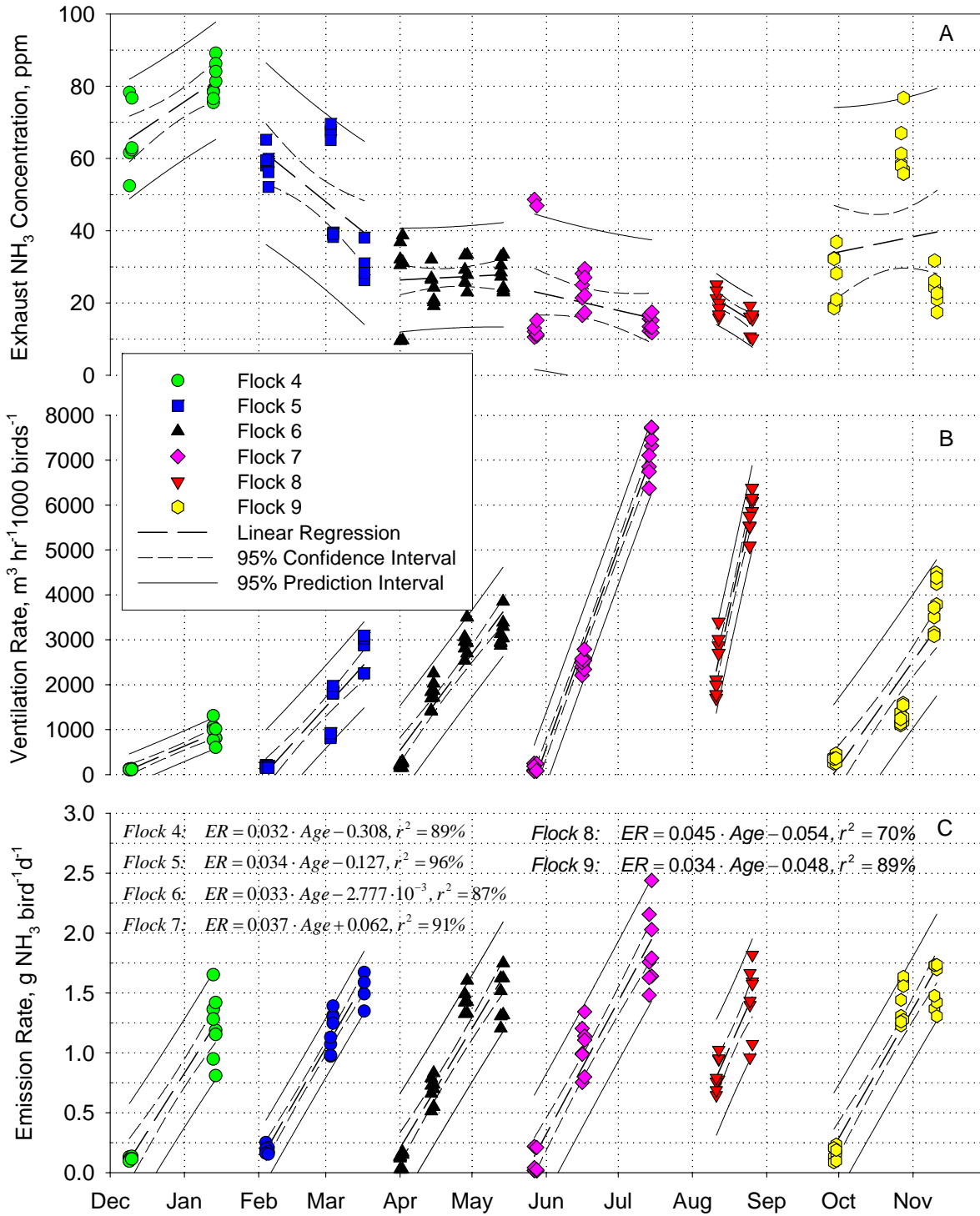


Figure 3. Individual flock presentation versus date for Site 1 managed with built-up litter, except flock 7 on new litter (in three of four houses). Average daily ammonia concentration (A) and ventilation rate (B) for each flock cycle over the one-year study period. Average daily emission rate per bird is shown in C with individual flock regression equations.

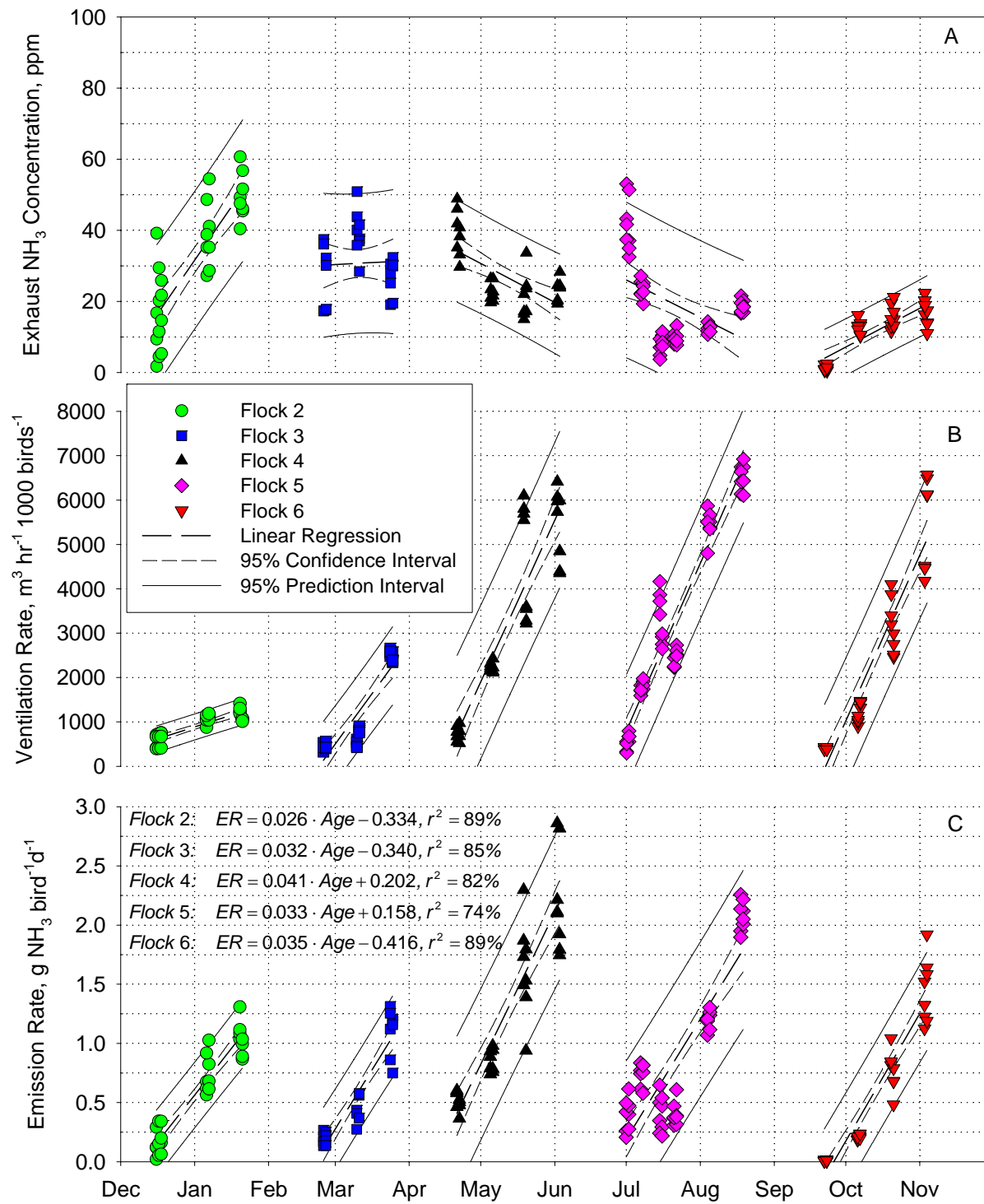


Figure 4. Individual flock presentation versus date for Site 2 managed on built-up litter, except flock 6 on new litter. Average daily ammonia concentration (A) and ventilation rate (B) for each flock cycle over the one-year study period. Average daily emission rate per bird is shown in C with individual flock regression equations.

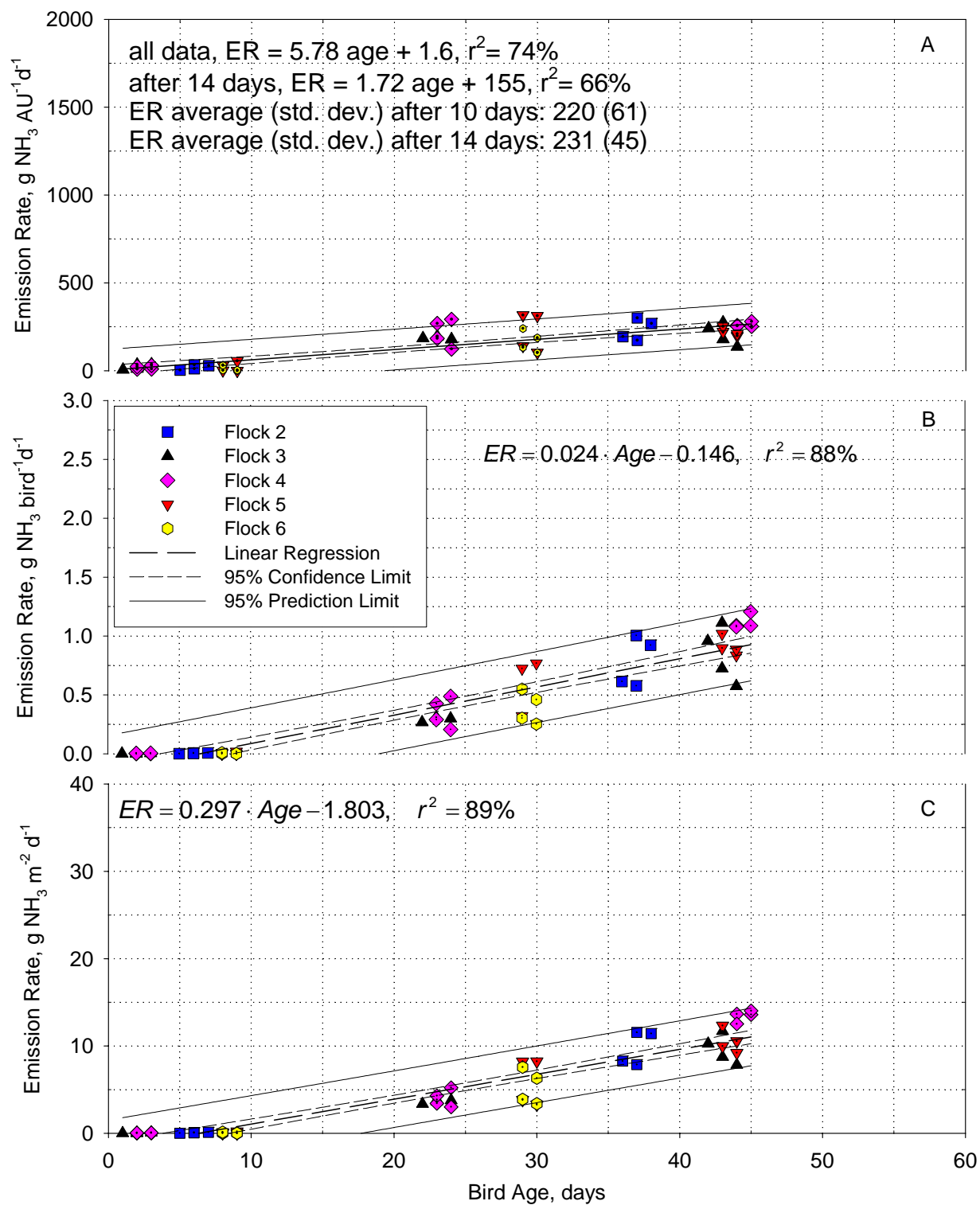


Figure 5. Composite of all flocks' emission rate for Farm H: Daily average emission rate expressed per 500 kg AU (A), per bird (B), and per floor area (C) for all study flocks.

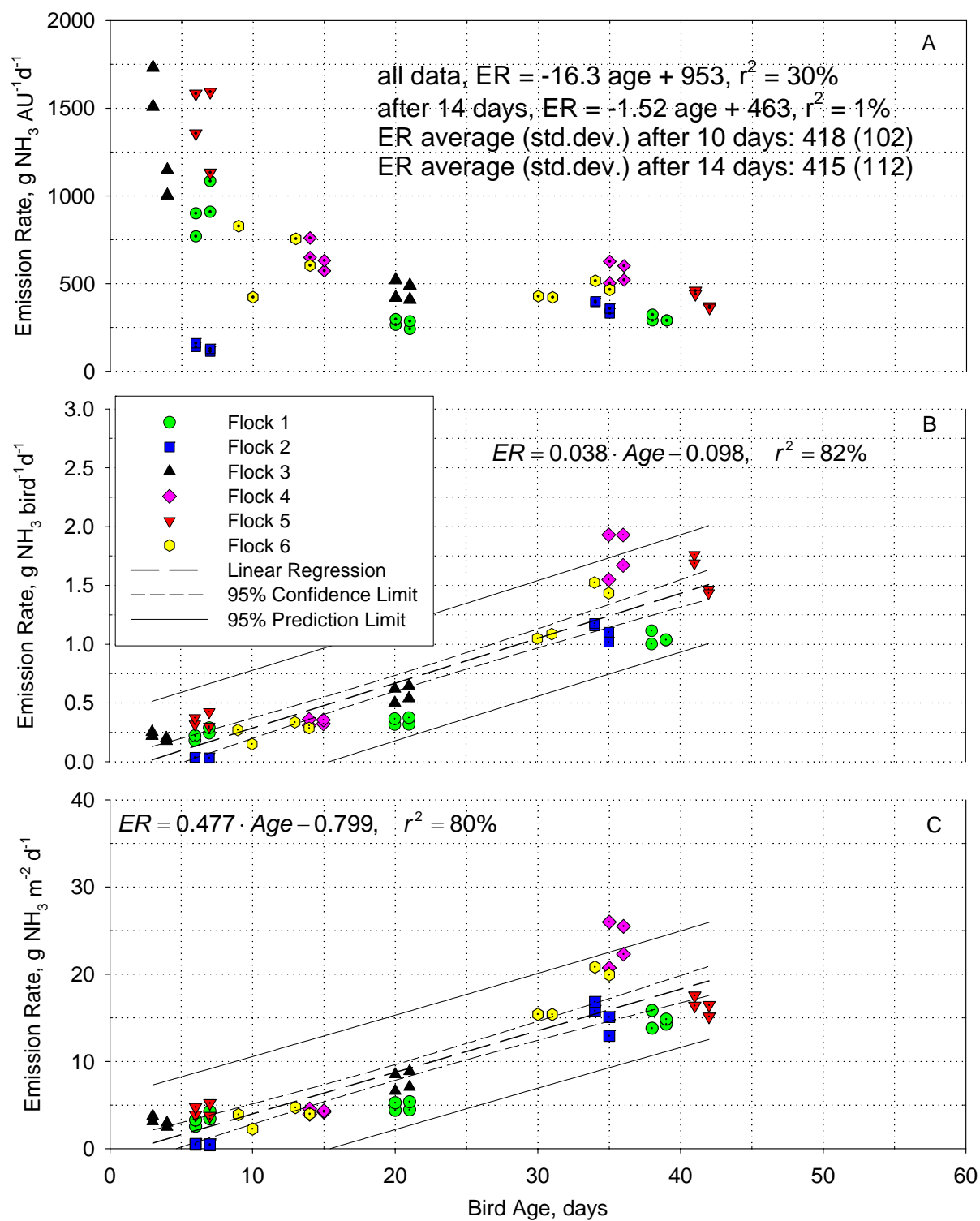


Figure 6. Composite of all flocks' ER for Farm B: Daily average emission rate expressed per 500 kg AU (A), per bird (B), and per floor area (C) for all study flocks.

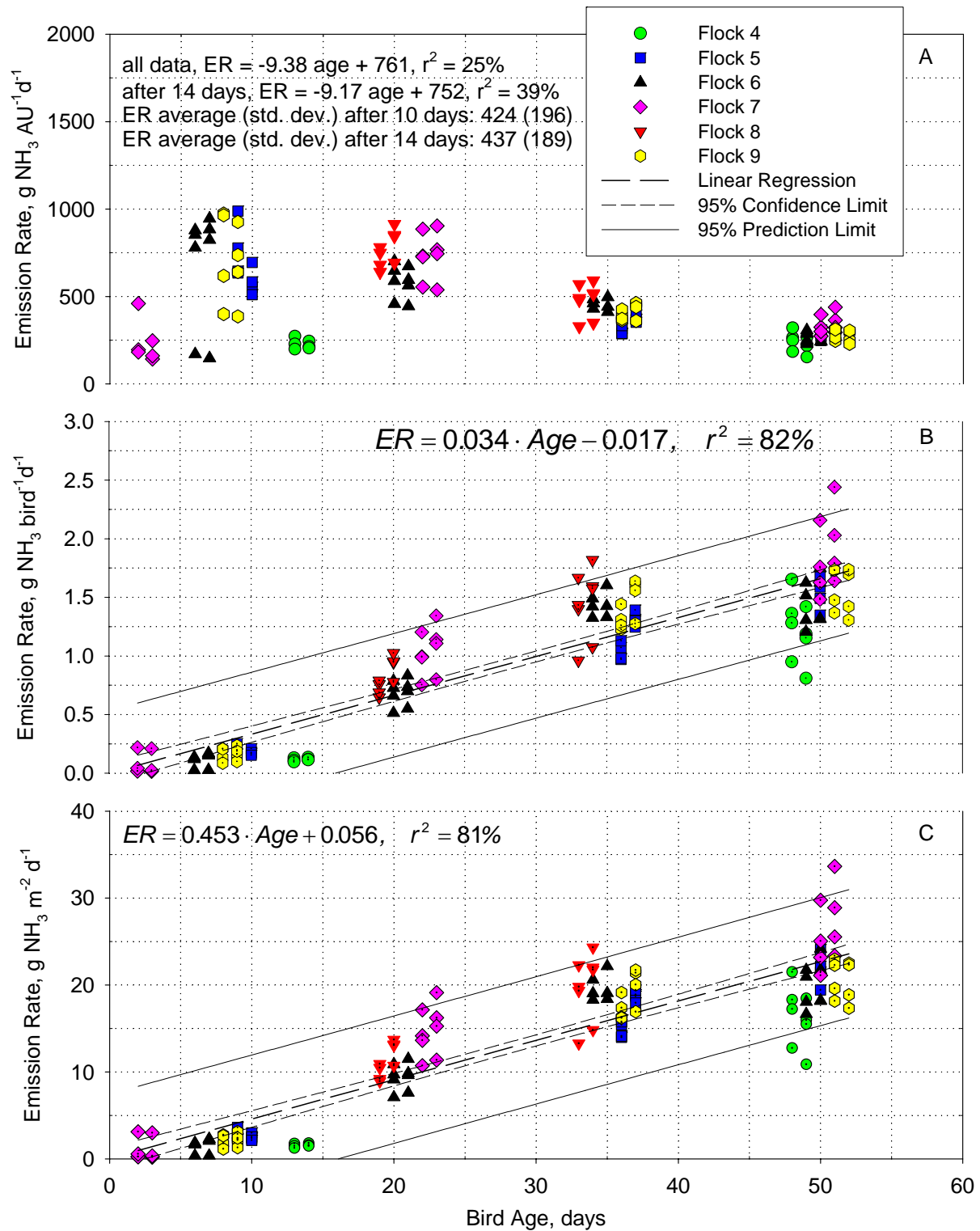


Figure 7. Composite of all flocks' ER for Site 1: Daily average emission rate expressed per 500 kg AU (A), per bird (B), and per floor area (C) for all study flocks.

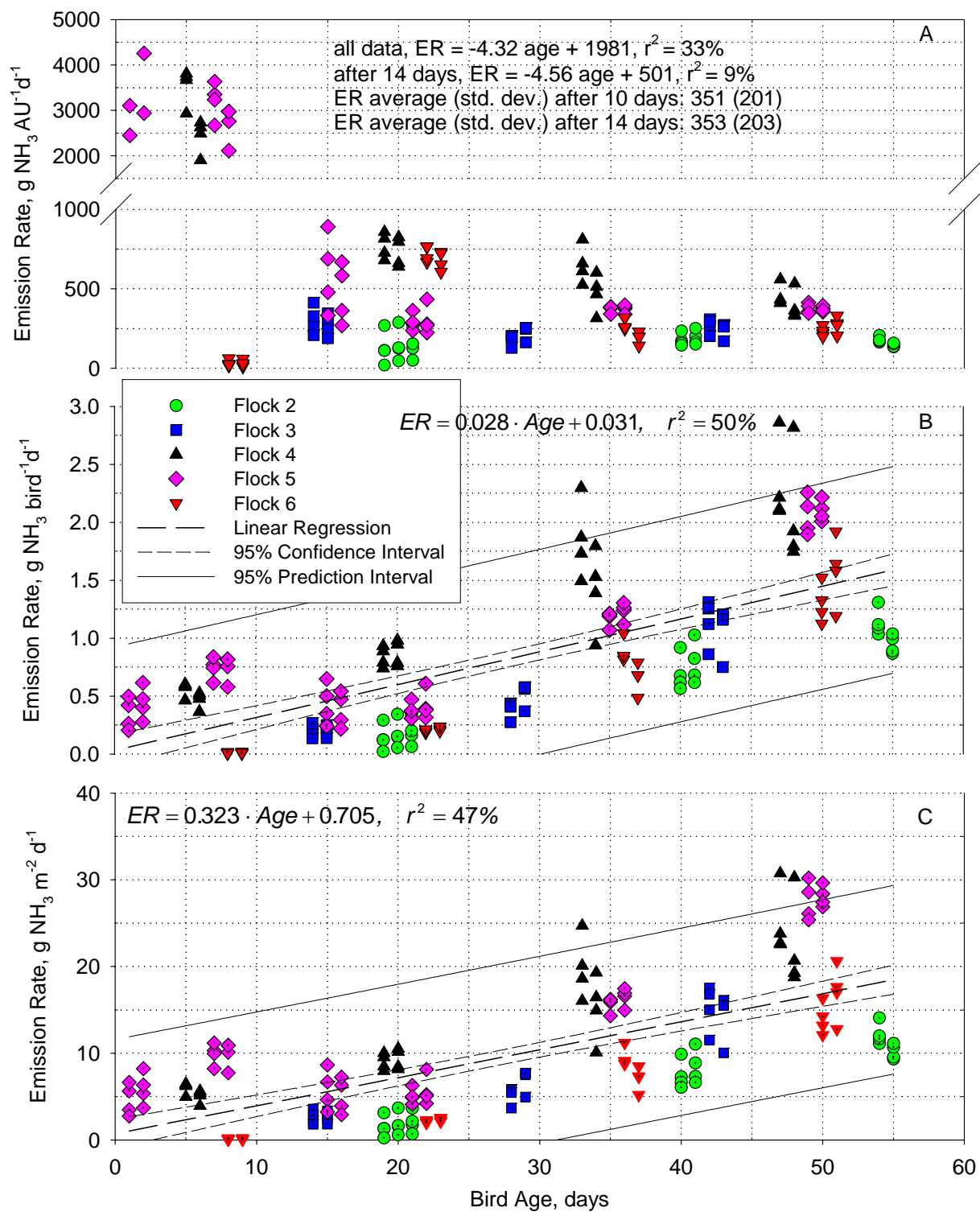


Figure 8. Composite of all flocks' ER for Site 2: Daily average emission rate expressed per 500 kg AU (A), per bird (B), and per floor area (C) for all study flocks.



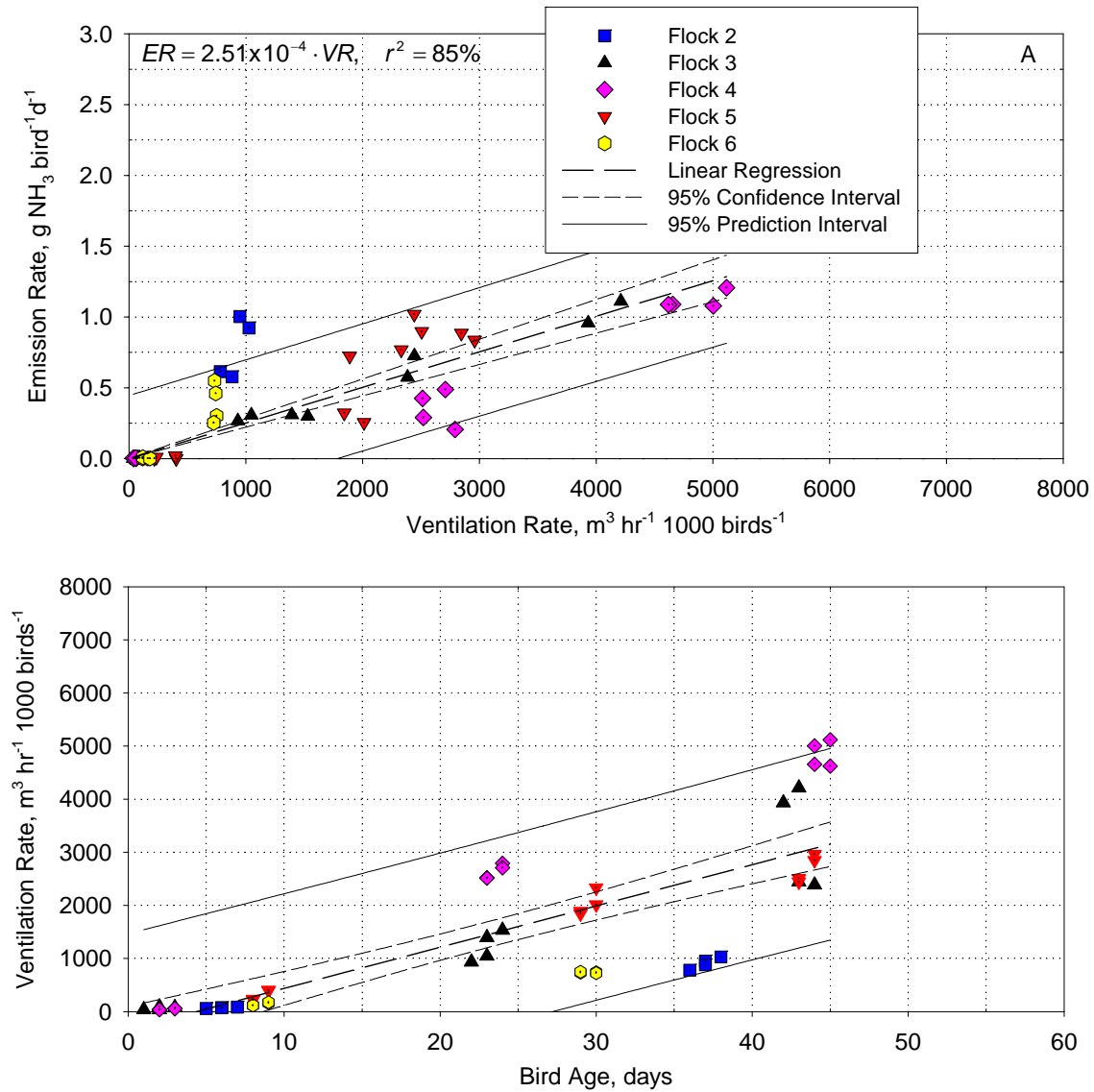


Figure 9. Emission rate composite of all study flocks at Farm H in terms of average daily house ventilation rate (A) and ventilation rate versus flock age (B).

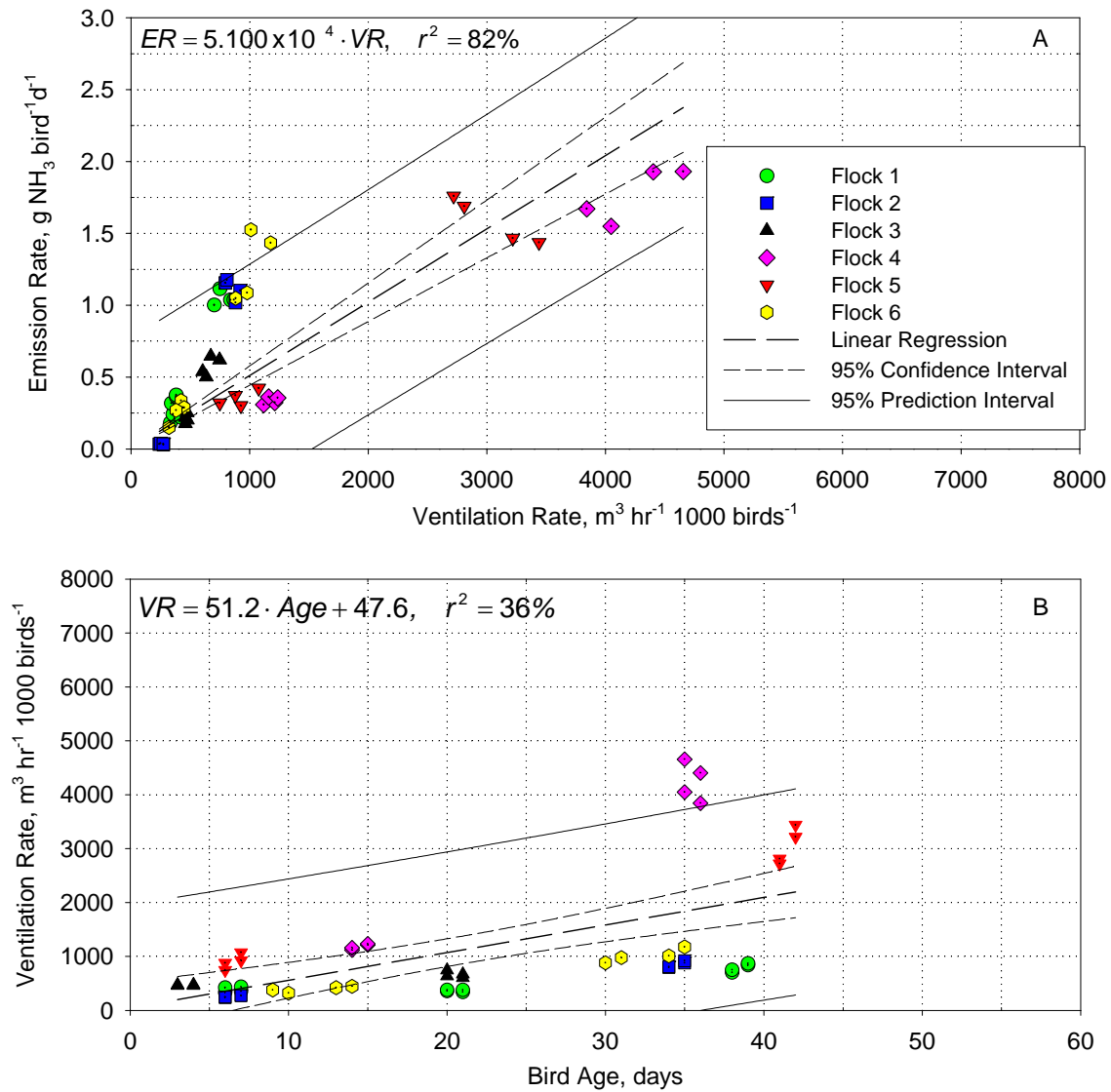


Figure 10. Emission rate composite of all study flocks at Farm B in terms of average daily house ventilation rate (A) and ventilation rate versus flock age (B).

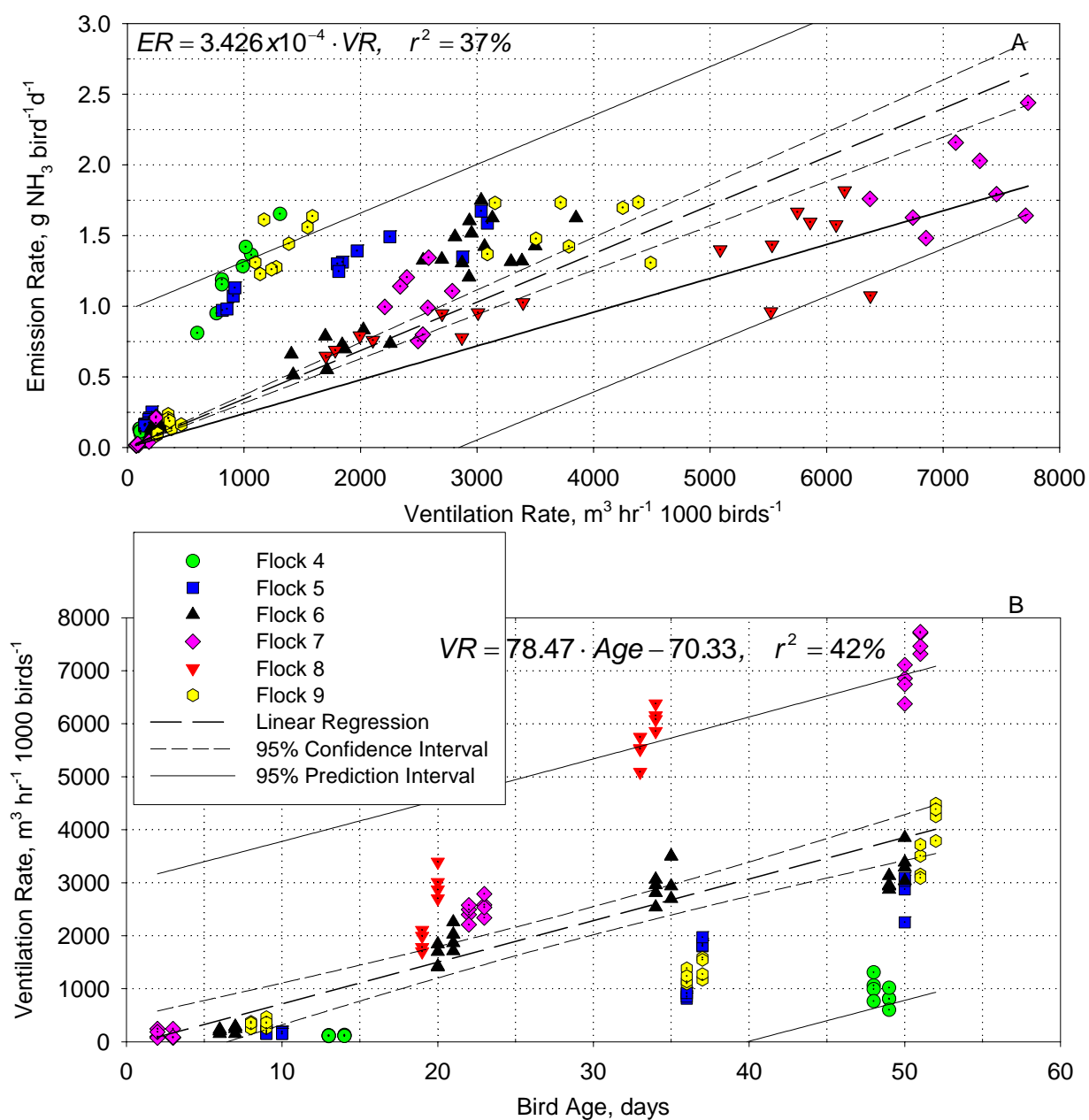


Figure 11. Emission rate composite of all study flocks at Site 1 in terms of average daily house ventilation rate (A) and ventilation rate versus flock age (B).

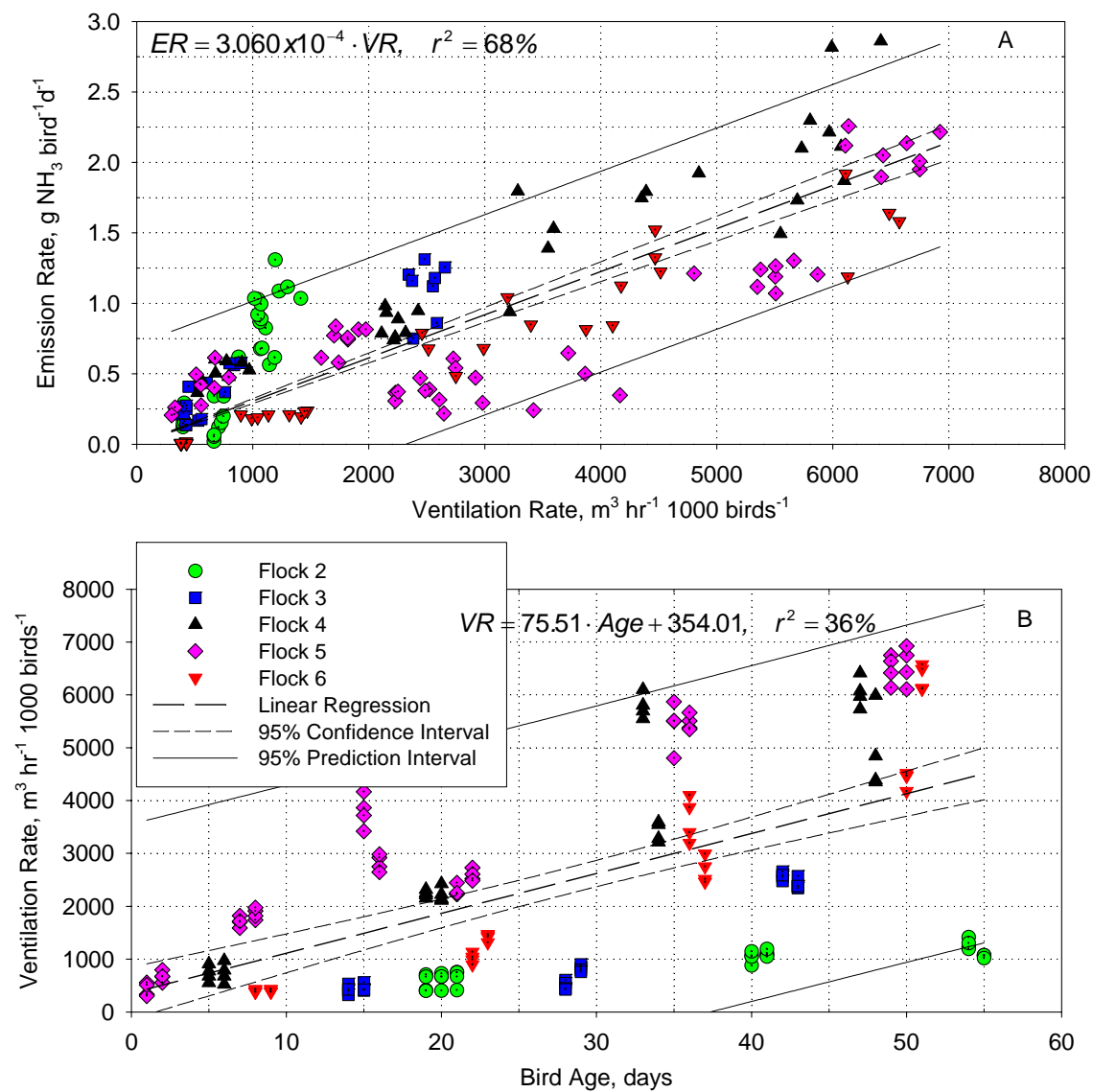


Figure 12. Emission rate composite of all study flocks at Site 2 in terms of average daily house ventilation rate (A) and ventilation rate versus flock age (B).